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Autonomous Energy Supply for Country Houses in Ukraine

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Abstract

The growing demand for energy independence and reliability in Ukraine, especially in rural areas, has intensified the interest in decentralized and autonomous energy systems. This trend is driven by frequent grid disruptions, regional disparities in energy access, and increasing household energy expenditures. This article examines the issue of autonomous energy supply for country houses in Ukraine. It focuses on assessing energy needs, selecting appropriate energy sources, and evaluating the efficiency of renewable technologies in the context of rising energy tariffs, economic instability, and climate change. The study aimed to analyze the potential of solar, wind, bioenergy, geothermal, and small-scale hydropower systems, considering the country's natural and climatic conditions. It analyzes the performance results of a residential solar power plant located in the village of Dovzhok, Kamianets-Podilskyi district, Khmelnytskyi region, for the year 2024. Special attention is given to hybrid solutions with backup power options, energy storage systems, and intelligent energy management for improved efficiency. The authors provide recommendations based on technical, financial, and local factors. The article will be useful for engineers, energy specialists, designers, and homeowners interested in reliable and environmentally friendly energy solutions. The findings highlight the practical benefits and limitations of various technologies under real-life conditions. They also emphasize the importance of integrated approaches in achieving sustainable and resilient residential energy autonomy.

Keywords

Autonomous energy supply; Renewable energy sources; Solar energy; Wind energy; Bioenergy; Geothermal energy

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Introduction

Over the past decades, the world has seen a trend where energy systems are transitioning to decentralized production focusing on the generation of electricity and heat from "small" sources (compact, stand-alone or local energy systems designed to supply power to an individual home or a small cluster of buildings independently of the central power grid). This transition is allowing consumers to use energy as active producers and participate in the energy market. In the 1990s, energy supply in Ukraine was based mainly on large power plants and centralized heating networks. However, since the beginning of the 2000s, the situation has changed dramatically. The growth in energy demand, increased attention to environmental problems, climate change, and cost reduction in renewable energy technologies have contributed to the transition to more flexible and sustainable solutions. In Ukraine, various technologies for decentralized energy production are already actively used, including rooftop solar power plants, wind generators, heat pumps, and local biomass boilers, which provide both electricity generation and heating.

In the conditions of modern Ukraine, autonomous energy supply of a country house is becoming increasingly relevant. The growth of electricity tariffs, frequent supply interruptions, and the urgency of finding ways to achieve energy independence encourage homeowners to look for alternative solutions. Instability of power grids, fan outages, and accidents due to system overload or adverse weather conditions have become a common phenomenon, especially in remote areas. Military actions have also caused the destruction of energy infrastructure, which forces many Ukrainians to look for ways to protect themselves from sudden power outages. The use of solar panels, wind turbines or hybrid systems reduces electricity costs while ensuring a stable supply throughout the year. Additionally, autonomous energy systems have great environmental benefits. The use of renewable energy sources reduces the burden on the environment by reducing carbon dioxide emissions and promoting the development of "green" energy. This is especially important in the context of global climate change and the need to transition to sustainable and regenerative energy production.

Ukrainians also receive state support in the implementation of alternative energy. There are financing programs and grants for the installation of solar stations, heat pumps and battery systems. This allows a significant reduction of initial implementation and installation costs, making energy independence more affordable. Given all of the aforementioned factors, autonomous energy supply is shifting from a trend to a necessity to ensure stability and safety in rural living. Modern technologies and policies are ensuring a balance between efficiency, reliability and economic feasibility. This study analyses and assesses the renewable energy sources, such as solar, wind, bioenergy, geothermal and hydropower technologies to determine the optimal technical solutions for ensuring energy autonomy of privately owned rural homes. The study explores the efficiency of modern energy storage and management technologies and provides evidence-based recommendations for selecting appropriate energy sources for country houses, about economic and environmental considerations.

Methodology

Methodology involves several key stages of research aimed at assessing energy needs, selecting optimal sources of autonomous energy supply, and analyzing the effectiveness of their application in the conditions of Ukraine.

Analysis of Energy Needs

Assessment of energy needs of a typical country house, utilising the online electricity consumption calculator of the Lvivenerhozbut company (Lvivenerhozbut, 2025). This tool shows the average electricity consumption, taking into account typical household appliances, their power and operating mode. The power assessment was carried out to calculate the appropriate energy supply for a typical country house under current conditions in Ukraine.

Selection and Analysis of Autonomous Energy Supply Sources

Analysis of several energy sources, including:

- *Solar energy:* The analysis of the characteristics of solar panels was carried out based on data from IKNET (IKNET, 2024) and UtemSolar (UtemSolar, 2025). The level of insolation (the amount of solar energy incident on a unit area of the Earth's surface over a defined period) in Ukraine and the effectiveness of utilising solar power stations for autonomous energy supply were examined. The analysis of the generation performance of a suburban home's solar power plant was conducted using the FusionSolar software application.
- *Wind energy:* The assessment of the efficiency of wind turbines was based on the research of Zalata O. (Zalata, 2024), as well as on regional climate data on wind speed.
- *Geothermal technologies*: The study of the cost and efficiency of geothermal systems was conducted using data from Alterair (Alterair, 2024).
- *Bioenergy:* The analysis of the possibilities of using biofuels and biogas plants was based on the works of Pecheniuk and Garasymchuk (Pecheniuk & Garasymchuk, 2024).
- *Mini-hydroelectric power plants:* The study of the possibility of using small hydroelectric power plants was based on the publications of Danylchenko A.O. (Danylchenko, 2020).

Cost and Economic Efficiency Analysis

The cost of implementing autonomous energy solutions was estimated based on market price data for equipment as well as installation costs (solar panels, wind turbines, and battery systems), including HUAWEI products and other alternative energy suppliers..

Research on Energy Storage Systems

The classification of battery systems was based on the research of Bula S. (Bula, 2023), which considered the efficiency of different types of batteries for private homes.

Intelligent Energy Management Systems (technologies that use automated algorithms to optimize energy consumption, supply, and storage, reducing costs and improving energy efficiency)

To increase the efficiency of autonomous energy sources, the use of intelligent energy management systems was studied, which allows for optimizing energy production and consumption (Stadnik *et al.*, 2025).

Energy Needs Assessment

To develop a set of measures to implement autonomous energy supply for a country house, an assessment of electricity needs was conducted. Energy-efficient planning allows for the optimization of consumption, reduction of centralised network dependence and increased living comfort. Table 1 shows the calculation of electricity consumption for a typical country house in modern conditions in Ukraine. The electricity consumption calculation was carried out for the conditions of the Kamianets-Podilskyi district in Khmelnytskyi region.

Table 1. Calculation of electricity consumption for a typical country house during the spring-autumn period

№	*Connected devices*	*Power, W*	*Number of devices*	*Working hours (per day), hours*	*Energy consumed (per day), kWh*
1	LED lamp	7	10	2	0.14
2	Monitor	40	1	2	0.08
3	Computer	350	1	2	0.7
4	Notebook	100	2	2	0.4
5	Printer	300	1	0.1	0.03
6	Scanner	100	1	0.1	0.01
7	TV	170	1	10	1.7
8	Refrigerator	250	1	24	6
9	Washing machine	1500	1	2	3
10	Microwave oven	1000	1	0.2	0.2
11	Electric kettle	2000	1	0.2	0.4
12	Electric stove	2000	1	1	2
13	Air conditioning	100	1	5	0.5
14	Iron	2000	1	0.2	0.4
15	Vacuum cleaner	1500	1	0.1	0.15
16	Boiler	1500	1	6	9
17	Hair dryer	1000	1	0.1	0.1
18	Total				24.81
19	Other appliances and devices (+20%)				4.962
20	Total				29.772
21	Number of days per month				30
22	Average monthly electricity demand				893.16

Source: Lvivenerhozbut (2025)

An important factor in planning electricity supply is seasonal fluctuations in the energy consumption of a country house, as the load on the system changes at different times of the year. The lowest indicators are observed in late spring and early autumn, when the need for heating is significantly lessened, and the intensive use of air conditioners has not yet begun. The impact on energy consumption, in addition to the level of economic activity, is largely determined by temperature conditions (Pro-Consulting, 2024). In winter, electricity consumption increases significantly due to space heating, the operation of electric boilers, heat pumps and additional lighting, since daylight hours are shorter. During this period, it is important to provide backup power sources to avoid problems with emergency shutdowns. In summer, the main load is created by air conditioning systems, pumping equipment for water supply and irrigation, swimming pools and other seasonal devices. At the same time, solar panels work most efficiently, allowing partial compensation for increased consumption. The spring and autumn periods are characterized by transitional regimes, when energy consumption changes depending on the air temperature. At this time, it is important to balance the use of different energy sources and take into account possible load fluctuations. A comprehensive approach to assessing seasonal changes allows for a more accurate calculation of the capacity of electrical installations, selection of effective energy storage systems and reduction of electricity costs in the long term. More detailed calculations are planned to be conducted in future studies.

Autonomous Energy Sources

In Ukraine, autonomous energy sources, including solar, wind, bioenergy, geothermal, and mini-hydropower systems, offer significant potential to reduce dependence on centralized energy supply. The choice of an appropriate solution depends on regional conditions, available resources, and environmental factors (Duras, 2018). Solar panels and wind turbines are versatile, while bioenergy and geothermal systems ensure a stable heat supply, and mini-hydropower plants work in suitable hydrological conditions. Backup generators provide reliability in emergencies. The development of these technologies will enhance energy independence, reduce costs, and mitigate environmental impact. Overall, the development of autonomous energy sources in Ukraine will contribute to increasing household energy independence, reducing energy consumption costs, and minimizing the negative impact on the environment.

Solar Power Plants

Solar energy is one of the most effective ways to provide an autonomous electricity and heat supply for a country house. Solar energy can significantly reduce dependence on traditional power grids, making a house more energy efficient and environmentally friendly. The basis of the system is solar panels that convert solar radiation into electricity. For a stable power supply to the house, electricity can be stored in batteries, which allows it to be used at night or during periods of insufficient sunlight. In addition, solar collectors that accumulate thermal energy can be used to heat water and maintain heating.

One of the main advantages of such systems is durability and minimal operating costs after installation. Solar panels serve for decades, without requiring complex

maintenance. At the same time, they provide an opportunity to significantly reduce electricity and heating costs, especially in conditions of constant growth in tariffs. However, like any technology, solar energy has its limitations. High initial investments can be a barrier to implementation, and the efficiency of operation depends on the region, the angle of inclination of the panels and weather conditions. In cloudy periods or in winter, energy generation is reduced, the optimal solution being a combination of solar panels with other energy sources, such as solid fuel boilers, heat pumps or backup generators.

Autonomous Solar Power Plants and Hybrid Solar Stations

Autonomous solar power plants provide energy without connection to the general electricity grid. The system consists of solar panels, an inverter, energy storage batteries and a controller. It allows for the production and storage of electricity for use at any time. The advantages of autonomous stations are complete independence from external energy supplies, ease of installation and operation, as well as the use of clean, environmentally friendly energy. However, the disadvantage is high cost, especially due to the need for batteries, limited efficiency during low solar activity, and the need for an emergency power source in case of prolonged cloudy periods (Haber *et al.*, 2024).

Grid-connected solar power plants are connected to the general electricity grid and allow the use of energy for personal consumption, while the excess can be sold to the state at a "green tariff". This is a profitable option for private homes where a stable supply of electricity is already available. Such a system consists of solar panels, an inverter and mounting hardware. It is ideal for those who want to reduce electricity costs and receive income from selling excess energy. The advantages of grid-connected solar power plants are: environmental friendliness, economic benefits due to the possibility of selling energy, ease of maintenance and silent operation. However, there are also disadvantages: high installation costs, dependence on solar activity (in winter or on cloudy days, efficiency may decrease), as well as the need to regularly clean the panels from dust and snow (Naumenko, 2019). Hybrid solar power plants combine the functionality of both grid-connected and autonomous systems. They are connected to the grid, but also have batteries to store energy, which allows them to be used during outages or at night. Such stations allow you to work at a "green tariff" and receive additional income from excess energy. The advantages of hybrid solar stations are the ability to customize the system to the user's needs, backup power during outages, as well as the ability to generate energy from different sources (sun and batteries). Among the disadvantages of hybrid stations are their high cost, longer payback period, and the need for additional equipment (Chynonova, 2022).

The choice between an autonomous, grid-connected, or hybrid solar station depends on the needs of the homeowner, budget, and location. If the consumer seeks independence from energy grids, then an autonomous station will be the best option. Grid-connected stations are suitable for those who want to receive income from the sale of electricity, and hybrid systems provide maximum flexibility, combining the advantages of both options. The price of a solar station for a country house depends on several key factors that affect the cost of equipment, installation, and system efficiency. First of all, the power of the station is decisive: the more electricity it produces, the more expensive the

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cost. For example, for an average household, stations with a capacity of 5 to 20 kw are often chosen, which can meet the needs of the family. If the system is to operate for personal consumption, as well as redeem benefits of a "green tariff", 30 kW or more is more suitable (Kryzhnyi, 2023). Another important factor is the choice of solar panels. Monocrystalline vs polycrystalline vs thin-film (Table 2).

Table 2: Characteristics of solar power plant panels

№	*Characteristics*	*Panel types*		
		Thin-film	*Monocrystalline*	*Polycrystalline*
1	Efficiency, %	12	25	20
2	Cost	Low	high	average
3	Service life, years	up to 3	20-25	20
4	Mass	Easy	heavy	average
5	Required area for production of 1 kw, m2	8	7	18
6	Solar radiation angle, degrees	–	90	–
7	Expediency of use	Private houses	Private homes, industrial enterprises	Industrial enterprises

Source: IKNET (2024)

Monocrystalline modules have a higher efficiency and longer service life, but are more expensive. Polycrystalline panels are cheaper but less efficient. Thin-film options are used less often due to their low efficiency compared to other technologies. An equally important component is the inverter, which converts the direct current generated by the panels into alternating current suitable for household use. There are three possible options here: grid-connected, hybrid and stand-alone inverters. Grid-connected systems are connected to the general electricity grid and allow the selling of excess energy. Hybrid models can work with batteries, and stand-alone stations use only their generation and stored energy (Avenston, 2023). In the instance of needing energy provision without connecting to a centralized grid, the purchase of batteries is necessary. This significantly increases the cost of the system, since high-quality lithium-iron-phosphate batteries are expensive. However, they ensure the stable operation of the station at night or in cloudy weather. It is also worth considering additional installation costs, which include fasteners, cables, protection systems and equipment installation. Installation costs may increase if the roof is of complex construction or if a preference for a ground station is preferred, as it requires a foundation.

Estimated prices for solar power plants for country houses in Ukraine as of early 2025 are shown in table 3.

Table 3: The cost of HUAWEI solar power plants

Indicator	*Power of the station, kw*							
	5	8	10	12	15	17	20	30
Price, USD	4000	4800	7000	7200	8640	10200	12000	18000

Source: UtemSolar (2025)

The final cost depends on the choice of equipment, the method of operation and additional installation conditions. In 2024, we analyzed the results of the operation of a solar station at a country house in the village of Dovzhok, Kamianets-Podilskyi district, Khmelnytskyi region. The power station occupies an area of 6*12=72 m^2 (Figure 1).

Figure 1: Solar power plant at a country house in the village of Dovzhok, Kamianets-Podilskyi district, Khmelnytskyi region (Photo by Andrii Pecheniuk)

The maximum design load is 30 kW. The volumes of generated energy by month are shown in figure 2.

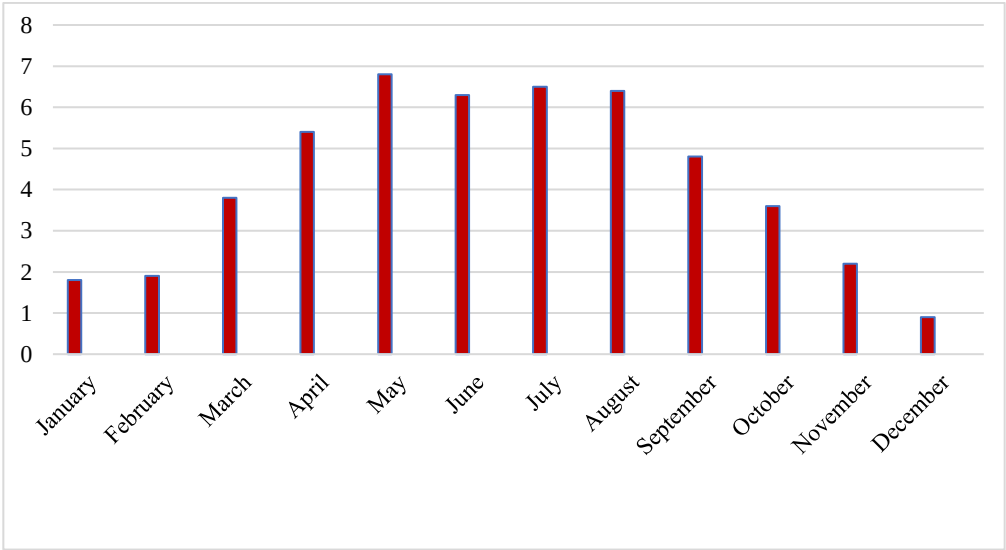

Figure 2: Electricity generation volumes by a solar power plant in 2024, MWh

In total, in 2024, the solar station produced 48.41 MW of electricity. All of it was sold at a "green tariff" of 160.6 USD. Thus, the owner of the country house received an income of 7774.65 USD per year (on average, 647.89 USD per month). The total cost of purchasing and installing the station is 24500 USD. In this instance, the payback period was 3.2 years (24500/7774.65).

Wind Energy

In regions with stable and strong (moderate) winds, a wind farm can be a good option for partially providing country houses with electricity. Its efficiency depends on factors that include climatic conditions, terrain, etc. If the house is located far from the centralised power grid, installing a wind generator can be a cost-effective solution in the long term. Such systems usually work in conjunction with batteries, which accumulate energy for use during periods of weak winds. The experience of Ukrainian specialists in the field of renewable energy shows that the best results can be achieved by combining wind energy and solar panels. During the day, when the sun is shining, the solar farm works, and at night or in windy weather, the windmill produces energy (Buduemo, 2024). This allows an efficient balance in energy supply at different times of the year and in different weather conditions. If the house is connected to the electricity grid, the wind generator helps reduce electricity costs by producing part of the required energy.

Main Factors Affecting Wind Generator Efficiency (Zhurba, 2021):

1. Wind speed and stability. A windmill is effective at an average wind speed of 4-5 m/s and above. If the speed is lower, generation will be minimal, and if the wind is too strong (over 20 m/s), the generator can automatically stop to protect against damage.
2. Installation height. The higher, the better. The optimal height is 10-30 meters (depending on the landscape and wind speed). In lowlands or among trees, the wind is unstable, which reduces efficiency.
3. Generator power. Wind turbines for country houses, 1-10 kW:
   – 1-3 kw are suitable for a small house or cottage.
   – 5-10 kw - provide energy for an average house with household appliances.

To create a full-fledged hybrid power plant, in addition to a wind generator, a charge controller, a battery, an inverter and a tower are also required. The equipment is selected individually, taking into account the specifics of the materials, budget and technical requirements. A ready-made 5 kW wind power plant kit, including a turbine, a 6 kW inverter, an uninterruptible power supply and a 5 kWh battery, can be purchased for 4 thousand US dollars. Installation, depending on the complexity, will cost an additional 500 to 1000 dollars. The costs of small wind power plants with a capacity of up to 20 kw are usually repaid as a "green tariff" within 10 years (twice as long as solar installations). This is due to the higher cost of equipment and the complexity of installation, which requires expensive engineering solutions. A wind turbine with a nominal power of 10 kW can provide power only if there is sufficient wind force. Ukrainian manufacturers are guided by an average speed of 8 m/s, European manufacturers ones 10-12 m/s, and Chinese manufacturers ones 10-15 m/s. The

efficiency of high-quality wind turbines is 30-40% (Zalata, 2024). According to Ukrainian legislation, private homeowners can install wind turbines with a capacity of up to 30 kW and a height of no more than 30 meters without the need for special permits or licenses. In this case, wind turbines must emit noise within 34-45 dB.

Wind turbines in Ukraine are not yet able to completely replace a centralized power supply or become commercially viable, but they significantly support consumers during power outages and have some advantages over solar power plants. They operate continuously regardless of the season, and in winter, when solar energy is ineffective, their role is especially important. For example, the 1.6 kW Flamingo 4.4 wind turbine provides about 30% of the energy needs of a small shop owned by entrepreneur Serhiy Horpynych in the Zaporizhia region. According to SolarWind Systems, generating 0.8 kW of wind energy on a typical winter day is equivalent to the output of a 20–25 kW solar power plant (Bilozerova, 2021).

Generators

With the beginning of a full-scale war in Ukraine in 2022, the need for generators as an autonomous power supply for residential and industrial facilities has considerably increased. A generator is a device that converts the mechanical energy of an internal combustion engine into an electric current. An electronic unit that regulates the current parameters, providing an output voltage of 220 V and a frequency of 50 Hz (Shyrokun, 2023), is essential for operation. To provide electricity to a country house, there are multiple fuel options: gasoline, diesel, gas or hybrid.

Gasoline generators are an affordable option, especially for short-term use, for example, in the case of an emergency power outage. They are easy to start and operate without the characteristic diesel noise. However, gasoline models have high fuel consumption and a limited engine life, which usually ranges from 3,000 to 5,000 hours. Diesel generators are durable, as they can operate for up to 30,000 hours. They are more economical for long-term use, but require periodic loads to avoid the formation of carbon deposits when idling. Their disadvantages include increased noise levels, higher cost, and the need for winter fuel heating to ensure stable operation in the cold season. Gas generators operate on natural or liquefied gas, such as methane or propane-butane. They are the most environmentally friendly option due to minimal emissions of harmful substances. These models are also distinguished by quiet operation and cheaper fuel. At the same time, their operation requires a stable supply of gas through cylinders or a main system. Hybrid generators provide flexibility in use, as they can operate on several types of fuel, for example, gasoline and gas. This makes them particularly useful in conditions of unstable fuel supply, allowing switching between different energy sources depending on availability (Moisieiev, 2022).

Thus, the choice of generator depends on the specific needs of the user, operating conditions and fuel availability. According to the principle of operation, a distinction is made between traditional and inverter generators. Traditional generators, which can be synchronous or asynchronous, are the most common for basic needs. Synchronous generators – work in sync with the grid frequency, are used in large power plants, and require additional equipment to operate. Asynchronous generators – run slightly faster

than the grid, are simpler to use, and are often used in wind and small hydro power plants. They provide electricity, but do not always guarantee a stable current frequency of 50 Hz. This can be critical for sensitive electronics that require a stable voltage for correct operation. Inverter generators are distinguished by the fact that they provide stable current without voltage fluctuations. This makes them the optimal choice for powering sensitive electrical devices such as computers, pumps or medical equipment. Although they are more expensive than traditional models, their efficiency, compactness, and cost-effectiveness make them a profitable option for users who need high-quality and reliable power (Smoliar, 2023).

When choosing a generator, the first thing to do is to determine its required power by calculating the total power consumption of all devices that will operate simultaneously during a power outage. Information about the power consumption can be found in the technical specifications of the devices. For the generator to work efficiently and not wear out prematurely, its power should slightly exceed the total load. For example using 50 to 75% of the maximum power. Powerful generators are costly and have a higher fuel cost. It is therefore not advisable to buy a device with an excessive margin. The most popular among Ukrainians are compact models with a capacity of 2.5-2.8 kW. Owners of private houses more often choose gasoline, diesel or dual-fuel (gas-petrol) generators with a capacity of 5.5 kW or more (Rykhlitskyi, 2022).

When calculating the required power needed, it is important to take into account starting currents. For example, compressor and pump engines can consume 2-3 times more power at start-up than in nominal mode. The price of a generator depends on its power and the type of fuel. The most affordable are gasoline models, the cost of which varies between 600-1500 USD. Diesel generators are more expensive - from 1000 to 6000 USD - but they are more economical in the long term. Gas models, which are distinguished by their environmental friendliness, cost between1200-8000 USD. Inverter generators, which provide a stable voltage range between 700 to 3000 USD.

In addition to the initial cost, operating costs should be taken into account, mainly fuel costs, which consume an average of 0.3-0.5 litres for each kilowatt-hour of electricity generated, regular maintenance, including filter replacement, oil, and spark plugs. A generator is a reliable option for autonomous power supply, but the choice depends on the needs of the house, budget, and fuel availability. Here are some suggestions:

– for backup power – a gasoline or diesel generator 5-10 kW;
– for long-term use – a diesel or gas generator 10-20 kW; and
– for maximum autonomy – a combination of a generator, batteries, and solar panels.

Bioenergy

One of the options for providing energy to a country house is bioenergy, which involves the use of renewable resources. Biogas plants and biomass cogeneration systems make it possible to obtain electricity and heat independently of centralized networks (Pecheniuk *et al.*, 2024).

Biogas plants are designed to process organic waste (food waste, manure and agricultural waste) into biogas, which can then be used to generate energy. This approach provides the possibility to obtain energy in tandem with the ability to reduce the amount of household waste. It should be noted that a biogas plant can be an effective source of electricity only if there is a sufficient amount of organic waste. It works on the principle of anaerobic decomposition of manure, food, and agricultural waste, forming biogas - a mixture of methane and carbon dioxide - as a result. The efficiency of a biogas plant depends on the amount and composition of the raw materials. For example, 1000 kg of manure can produce 30-50 m^3 of biogas, which is equivalent to 60-100 kWh of electricity. With a constant supply of raw materials, a medium-sized installation is capable of generating 1-5 kW of electricity, which is enough for basic household needs (Sydorchuk, 2020). One of the key factors is the high initial installation costs, which start at 2000 USD and can be significantly higher depending on the capacity of the installation. It is also important to consider the need for regular maintenance and control of the fermentation process. The system requires maintaining optimal temperature and humidity for effective gas formation, as well as periodic cleaning of the tanks from residues.

The use of biomass cogeneration units that run on firewood, pellets or other types of wood waste is another alternative. This approach allows you to significantly increase energy efficiency, since during biomass combustion, both heat and electricity are generated simultaneously. This allows the use of fuel with maximum benefit, reducing energy loss. The main advantage of this option is the ability to use affordable and renewable fuel - wood chips, pellets, agricultural waste or other biomass. Inexpensive access to these resources can significantly reduce the cost of energy supply to the house. In addition, biomass cogeneration helps reduce CO_2 emissions compared to traditional gas or diesel generators, which makes it an environmentally attractive option (Humentyk, 2016).

However, as with all options, there can be disadvantages. Firstly, the high initial cost of equipment can be a hindrance- depending on the capacity, the price of a biomass cogeneration plant can vary from 15,000 to 50,000 USD. In addition, it is necessary to provide a place for storing fuel, which can be a problem for houses with limited space. Additional costs may also arise due to the need for regular maintenance: cleaning the boiler, controlling combustion and ensuring uninterrupted supply of biomass. The feasibility of using such an installation depends on the conditions of a particular house. If the area is large, there is a constant demand for heat, and biomass is available at a low price - cogeneration can quickly pay for itself. In the case of small houses or unstable heat load, the installation costs may be unjustified.

The last three years Ukraine has seen a rapid increase in the use of generators in the private sector. The main reason was the massive attacks on the energy infrastructure, which caused frequent and long power outages. In response, the demand and availability of generators increased - imports increased significantly, and different models appeared on the market for different needs and budgets. At the same time, the trend towards energy independence has intensified, as Ukrainians seek to have backup power in case of new blackouts. State and volunteer initiatives have also contributed to the spread of

generators, especially in the affected regions. Even after the stabilisation of the power supply, many households kept generators as a backup solution.

Geothermal and Thermal Energy

Geothermal energy is a modern and effective way to provide a country house with heat, hot water and even air conditioning. It is based on the use of the Earth's heat, which is stored in the soil or groundwater. The main technology used in private homes is a geothermal heat pump (Panchuk, 2024). The principle is quite simple: at a depth of 1.5 to 2 meters, the soil temperature remains relatively stable throughout the year, fluctuating within the range of +7…+12°C. The geothermal pump extracts this heat, increases its temperature using a compressor and transfers it to the house's heating system. In summer, this process can work in the opposite direction - the system absorbs heat from the house and transfers it to the soil, ensuring natural cooling of the premises. Depending on the conditions of the site and the needs of the owner, geothermal systems can be implemented in three versions: horizontal, vertical or water. The horizontal system involves laying pipes to a depth of 1.5-2 m, which requires a significant land area. The vertical system involves drilling wells to a depth of up to 150 m, which allows the use of natural heat in deeper soil layers even in small areas. If there is a reservoir nearby, you can use a water circuit, which provides the highest efficiency, because water conducts heat better than soil (Portillo, 2024).

The advantages of a geothermal system are its high energy efficiency and savings on heating costs. Spending 1 kW of electricity, a geothermal pump is able to produce 3-4 kW of thermal energy, reducing the cost of heating a house by 50-80% compared to traditional systems that run on gas or electric boilers. In addition, the system is environmentally friendly, as it does not create harmful emissions into the atmosphere (Morozov, 2022). At the same time, it is worth considering some disadvantages. The main deterrent is the high initial cost of installation. The price of a turnkey geothermal heating system rests on various factors. – depth and number of wells;

– drilling costs;
– length of pipelines and type of geothermal circuit (vertical or horizontal);
– choice of additional equipment;
– complexity of installation and commissioning work;
– brand and characteristics of the equipment.

The final cost is calculated individually for each house. For example, installing a geothermal system for a house with an area of 250 m² will cost from $ 25,000 (Alterair, 2024). It should be noted that geothermal heating is especially profitable for large houses used as a permanent residence. The payback period of such a system is usually from 5 to 10 years, which makes it a promising solution for those who plan to residein their house for a long time. Geothermal energy for country houses in Ukraine is profitable in the long term, but requires a significant initial investment. It provides heating and cooling efficiently, especially in well-insulated houses, and can be economically viable for those who plan to live in the house for many years. However, the high cost of installation, the need for space for horizontal collectors or drilling for vertical systems make it less attractive for those looking for a quick and cheaper solution. Geothermal energy will be optimal for new buildings and owners ready for long-term investments in

energy independence, but it is not the best option for those who do not plan to live in the house for a long time or have a limited budget.

Mini-Hydroelectric Power Plants

If there is a permanent source of running water on/or near a country house plot – a river, stream or even a small waterfall – a mini-hydroelectric power plant (mini-HPP) can be an effective solution as an autonomous energy supply. Such a system operates uninterrupted, unlike solar panels or windmills, and providesa stable source of electricity regardless of weather conditions. The principle of operation of a mini-HPP is to harness the energy provided by the movement of water to rotate a turbine, which drives a generator to produce electricity. Water can be supplied directly to the turbine through the river as the source in the case of a run-of-the-river system (the power plant uses the natural flow of the river without a large reservoir) or can be accumulated in a special tank, which can regulate the flow and improve the efficiency of the installation. For greater autonomy, a mini-HPP can be combined with a battery system, which will ensure the accumulation of energy and its use during periods of low water levels (Danylchenko, 2020).

One of the main advantages of such a system is autonomy – the homeowner receives an independent source of electricity without the need to connect to the general power grid. In addition, a mini-hydroelectric power plant has low operating costs: after installation, it practically does not require maintenance. This method of generating electricity does not involve emissions into the atmosphere and has a minimal impact on the environment (Vovchak, Teslenko and Samchenko, 2018). The biggest limitation is the availability of a water source - the flow must have sufficient speed and volume to ensure stable electricity generation. It is also worth considering the high initial cost, which can vary from 5,000 to 30,000 USD depending on the complexity of the installation and the type of system chosen. In some cases, it may be necessary to obtain permits for the use of water resources, which also affects the implementation of this option.

A mini-hydroelectric power plant is an ideal solution for country house owners who have access to a suitable water flow and seek to obtain an independent, reliable and environmentally friendly source of electricity. Among benefits is the reduction of electricity costs and the possibility to fully meet the house's electricity needs, which makes it a promising option for long-term use. It should be noted that the use of small hydropower plants (mini-HPPs) for the needs of suburban homes in Ukraine remains limited due to several factors. The construction of mini-HPPs requires significant investments, which can reach tens of thousands of dollars. This makes them less attractive compared to solar panels or wind turbines, which have a lower entry cost and simpler installation.

Legal and bureaucratic challenges also play an important role. In Ukraine, there are legislative restrictions on the use of natural water resources, and the process of obtaining the necessary permits can be complex and time-consuming. This further complicates the implementation of such projects for private households. In addition, many homeowners are simply unaware of the possibility of installing mini-HPPs or consider this technology too complex. The lack of widespread information and experience in the adoption of such

systems reduces interest among potential consumers. Despite these challenges, mini-HPPs remain a promising solution for homeowners with access to a stable water flow. Government support programs, simplification of approval procedures, and technological advancements could make them more accessible and popular in the future.

Energy Storage Systems

An important component of the autonomous energy supply of a country house is the use of an autonomous power supply system that stores energy in batteries. Such systems can be charged from the network during periods when electricity is available, and then provide power during outages. These systems are often used in combination with solar panels, wind farms and other alternative energy sources, making the possibility of a completely autonomous power supply system attainable. Battery systems can be used both to support the operation of individual devices and to power the entire house. They do not make noise like generators and do not require fuel, which makes them convenient and environmentally friendly.

The main components of a battery power system are:

- Battery – a key component that stores energy; its capacity determines how much electricity is available during outages.
- Charge controller – controls the supply of energy to the battery, preventing overvoltage and helping to extend its service life;
- Inverter – converts direct current coming from solar panels, wind farms or batteries into alternating current to power electrical appliances;
- Monitoring system – provides control over the system operation and timely notification of possible malfunctions.

The modern market offers various types of batteries, each of which has unique characteristics and purpose (Bula, 2023):

1. Gel (GEL) – lead-acid batteries with gel-like electrolyte. They withstand deep discharge well, are suitable for frequent autonomous power supply. Disadvantage: not suitable for buffer mode, expensive and sensitive to short circuits.
2. AGM (Absorbed Glass Mat) – electrolyte absorbed in a fibre glass matrix. Ideal for buffer mode, durable, and does not have a “memory effect”. Disadvantages: poor tolerance to recharging.
3. Multigel (MGEL) – an intermediate option between GEL and AGM. Withstand deep discharge and have better recombination of active substances.
4. Carbon-lead plates with the addition of carbon, which reduces the risk of overheating. They have a service life of up to 15 years, but require a special charging mode.
5. Lithium-ion (Li-Ion) - compact, quickly charged, does not have a "memory effect". Withstand many cycles, but are sensitive to temperatures and can overheat.
6. Lithium-iron-phosphate (LiFePO4) - reliable, thermally stable, durable, tolerate high currents and temperature fluctuations well. Ideal for backup power for electronics.

The system's performance depends on its settings and energy sources. If the house is equipped with solar panels or a wind farm, the batteries can store excess energy that is used in the evening or during power outages. If the system is connected to the public electricity grid, it can be charged during off-peak hours and use the stored energy during peak periods, which reduces costs. Choosing the right backup power system requires an analysis of electricity consumption. It is important to assess which devices need to be powered and for how long. This will help determine the required battery capacity and inverter power. Battery types are an important factor to consider. Lead-acid models are a budget option, easy to maintain, but have a shorter service life. Lithium-ion batteries are characterized by high energy density with low-frequency maintenance, although their cost is higher. Lithium iron phosphate batteries have a longer service life, stable operation and increased safety, but their initial cost can also be significant.

An important selection criterion is the battery's discharge capacity, which affects its efficiency. Lithium models allow you to use a higher percentage of the stored energy without compromising battery life. Before buying, it is important to verify the compatibility of all components; inverters, battery and charge controller must work as a single system. In addition, safety features such as protection against overheating, short circuit and overload are highly recommended. Technical support for set up instructions, maintenance and troubleshooting malfunctions is also recommended. Some modern systems offer remote monitoring via mobile applications, which greatly simplifies operational conditions. A competent approach to choosing a backup power system will help ensure a stable power supply, optimize costs and increase comfort in a country house.

Intelligent Energy Management Systems

It is important to recognize that given the current advancements inenergy technology development, the implementation of intelligent energy management systems (IEMS) in households is increasingly accessible. These systems integrate technologies for energy generation, storage and optimal utilization, enabling households to achieve autonomy, efficiency and cost savings (Stadnik *et al.*, 2025). The basic components of IEMS are:

- Distributed generation - solar panels, wind turbines, mini-hydroelectric power plants (if there is a reservoir);
- Energy storage systems - batteries for storing electricity;
- Smart consumption management - sensors, controllers and algorithms for optimizing electricity use;
- Automated heating, ventilation and air conditioning systems - heat pumps, electric boilers;
- Grid integration - bidirectional meters andthe option of selling excess energy at a "green tariff".

A key component of this system is the use of intelligent inverters and controllers that automatically control energy distribution. These inverters "determine" whether to feed excess electricity into the grid, charge batteries, or directly power consumers. More complex systems can also integrate the electricity grid, facilitating the re-selling electricity to the supplier or reduce utility costs (Sukhodolia, 2022). Automation systems and the 'Internet of Things' are used to effectively manage all these processes. Smart

meters, sensors, and software allow real-time monitoring of energy consumption, turning devices ‘on’ or ‘off’ depending on tariffs or the current load on the system. For example, on a sunny day, the system can automatically activate electric vehicle charging or water heating to reduce load during peak hours.

Another important component is intelligent climate control. Modern homes are equipped with heat pumps that can operate for heating in winter and cooling in summer, consuming minimal electricity. Combined with smart thermostats and temperature sensors, the system automatically regulates the indoor microclimate, which significantly reduces energy costs. All of these technologies are combined into a single intelligent energy management system allowing country house owners to control all processes via a mobile application or computer program. This system provides analytics on energy consumption and production, and optimizescosts according to changes in weather, tariffs, or the house's operating mode (But, 2024). Thanks to such solutions, a modern country house can become almost completely energy-independent additionally to beingprotected from power outages. This is not only a practical but also an ecological approach to energy consumption that meets modern trends in sustainability.

Conclusions

Autonomous energy supply for a country house in Ukraine is a promising solution that allows owners to reduce dependence on centralized energy networks and ensure the stability of electricity supplies. To achieve this goal, it is necessary to take into account the energy needs of the house, the climatic conditions of the region, as well as available energy sources. Among the various sources of autonomous energy supply, renewable technologies warrant special attention. Solar power plants hold significant potential due to the ample solar insolation available in most Ukrainian regions. Wind power also presents an effective solution, particularly in the southern and coastal areas (Odesa, Mykolaiv, Kherson, and Zaporizhzhia regions), where wind speeds allow for stable electricity generation. Diesel or gas generators can serve as backup energy sources, ensuring an electricity supply in conditions of low generation from renewable sources. Additionally, bioenergy emerges as a promising option especially in agricultural regions where biomass is available for energy production. Geothermal and thermal systems, particularly heat pumps, can significantly reduc heating and hot water costs by harnessing the energy from soil or water bodies. For homeslocated near rivers, constructing a mini-hydroelectric power plants can provide a constant and reliable energy source.

The effective operation of an autonomous system relies on energy storage solutions that enable the retention of excess electricity for use during periods of low production. Intelligent control systems play a crucialrole by automating energy consumption and distribution processes thereby minimizing losses and enhancing efficiency. Consequently, the integration of diverse energy sources, along with the implementation of modern storage and control technologies facilitates the development of a reliable and cost-effective autonomous energy system for country homes in Ukraine. The selection of specific solutions is influenced by regional characteristics, financial capabilities and the individual needs of homeowner.

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Conceived and designed the research or analysis	Yes	Yes	No	No	Yes	Yes
Collected the data	Yes	Yes	No	Yes	Yes	No
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